



AGRICULTURAL EXHAUST: A REASON TO INVEST IN SOIL

Alan J. Franzluebbers, Ronald F. Follett, Jane M.F. Johnson, Mark A. Liebig, Edward G. Gregorich, Timothy B. Parkin, Jeffrey L. Smith, Stephen J. Del Grosso, Michael D. Jawson, Dean A. Martens

Agriculture depends upon soil to serve as a medium for plant growth, as a reservoir of nutrients and water, and as a filter to detoxify chemical inputs. Soil of high quality contributes to the production of abundant, high quality food and fiber. Unfortunately though, poor management can exhaust soil.

Historically, soil has been degraded by poor management. Soil loss by erosion (wind, water, and tillage) has been, and continues to be, a major threat to soil sustainability around the world. Intensive tillage has been a traditional agricultural practice, but it is clear that it is not appropriate in many areas of North America, because it contributes to a high risk of erosion and losses of soil organic C and other nutrients. Soil productivity is also threatened by salinization from irrigation, contamination of soil with heavy metals, pesticides, and industrial byproducts, and suburban encroachment. Although soil resists degradation from some of these pressures, there is a point at which soil simply becomes exhausted and cannot continue to function normally. Economically, even a small loss of soil productivity could be detrimental for farmers operating on a small profit margin.

Management systems are needed to improve the quality of soil and restore its ecological functions. Soil conservation and restoration are investments that will benefit all sectors of society, because they will sustain soil productivity and improve environmental quality. Cleaner water and a more stable atmospheric composition of

greenhouse gases are environmental dividends that will naturally accrue with investments in soil. There is no better time to make those investments than now.

Modern agriculture is very energy intensive. Yet, agriculture exhausts only about seven to eight percent of the total greenhouse gases released in the United States and Canada (USDA, 2004; Environment Canada, 2006). Agricultural activities emit greenhouse gases by burning of fossil fuels, wood, straw, and other organic byproducts. The parts of plants that do not fully decompose are transformed into soil organic matter, and this accumulation of C can be called “soil C sequestration”. A major benefit of soil C sequestration is the development of healthy and productive soil. Decomposition of soil organic matter is a naturally occurring process, but is often accelerated in agricultural soils due to tillage, which results in significant exhaustion of CO₂ from soil. The process of soil C sequestration also helps offset the greenhouse effect by maintaining a healthier balance of more C in soil and less C in the atmosphere.

Why GRACEnet?

With years of data collected on an ad hoc basis by government, university, and private research institutions, best management practices have been and will continue to be promoted for improving soil functions, including the ability of soil to regulate gas emissions and sequester C (i.e., two counterbalancing natural

processes of exhaustion and investment). However, the coordinated effort of GRACEnet (Greenhouse Gas Reduction through Agricultural Carbon Enhancement network)—a new research project developed by the Agricultural Research Service (ARS) of the U.S. Department of Agriculture—provides a targeted scientific approach to study soil C sequestration and greenhouse gas emissions. It is a nationwide effort at multiple ARS locations to identify and develop agricultural strategies that will enhance the storage of organic matter in soil (i.e., C sequestration) and reduce greenhouse gas emissions. Results from the project will be used as a basis for C credit and trading programs, which could be used to reduce net emission of greenhouse gases and improve environmental quality.

Climate affects the potential of agricultural practices to mitigate greenhouse gas emission

Agricultural management impacts on soil organic C sequestration and greenhouse gas emission were recently reviewed on a regional basis as a foundation to build upon future research in the GRACEnet project (Franzluebbers and Follett, 2005). Soil resources and climate play major roles in the type of agriculture practiced. Climate, in particular, determines the type and amount of vegetation that occurs naturally and that can be managed. In general, soil organic C increases with increasing precipitation and decreasing

temperature, although variation in soil texture, type of vegetation, and drainage modify this generalization.

In the relatively large land area of western Canada and northwestern United States (cold, dry climate), soil organic C sequestration was highest under conservation-tillage management of cropping sequences that avoided traditional fallow periods (Liebig et al., 2005). Based on limited data, no-tillage management of irrigated crops could sequester soil organic C at five times the rate of no tillage in dryland cropping systems. The diversity of rangeland conditions in the region suggests a need for more research to obtain reliable estimates of management effects on soil C sequestration. A sizable database exists on nitrous oxide (N_2O) emission from agricultural soils in the region. Nitrous oxide emission was greatest in irrigated cropland and lowest in rangeland ecosystems.

In the region of eastern Canada and northeastern United States (cold, wet climate), distribution of organic C in the soil profile was altered with conservation tillage, but the total soil organic C stock did not change when compared with conventional tillage (Gregorich et al., 2005). Nitrous oxide emission has been fairly well characterized in the region, with winter/spring thaw events contributing nearly as much as growing season emission. Emission of N_2O was found to be greater in annual cropping systems than in perennial cropping systems. Uptake of methane (CH_4) by soils in the region was positive, but not large.

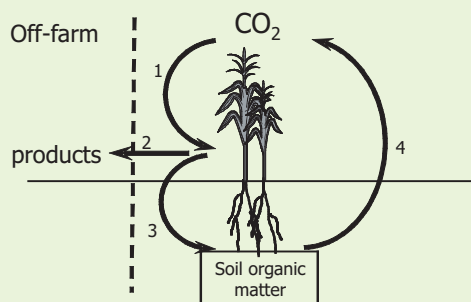
In the central United States (moderate climate), often called the breadbasket or Corn Belt of the United States, soil organic C sequestration with conservation tillage was relatively large (Johnson et al., 2005). Soil organic C sequestration

was even greater in more complex crop rotations than with continuous corn. Cover cropping may be a viable option to further enhance soil organic C sequestration in low-crop-residue-producing systems, but data to support this recommendation in the region are needed. Measurement of N_2O emission and CH_4 uptake by soils has been scarce in the region. Despite a significant portion of agricultural land in the region represented by pasture, there were too few data available to reliably assess the effects of management on soil C sequestration and greenhouse gas emission in the region for sod-based systems.

In the southwestern United States (hot, dry climate), agriculture is generally limited to irrigated croplands and beef cattle production on extensive rangelands. This region has a large pool of soil inorganic C (soil carbonates), which if dissolved, could greatly affect global warming potential by releasing CO_2 to the atmosphere (Martens et al., 2005). Several studies in the region have shown that conservation tillage can sequester soil organic C. Traditionally, irrigated land in the region has been intensively tilled, and therefore with conservation tillage, irrigated land could sequester a great deal of C in soil.

Rangeland condition in the southwestern United States has been variably affected

Carbon cycle on agricultural land



Carbon dioxide is absorbed by plants from the atmosphere (1), some of the carbon in the plants is removed from the farm in the form of the products harvested (2), and some is returned to the soil as residues and forms soil organic matter (3). Soil microorganisms decompose the plant material and CO_2 is released back to the atmosphere (4).

by historical overgrazing in the region. Restoring rangeland with more abundant forage and less intensive grazing has the potential to restore natural fertility and sequester soil organic C. It seems clear that the expanding human population in the region will largely determine how water will be distributed among competing sectors of the economy, which will affect land use.

In the southeastern United States (hot, wet climate), a large portion of land previously under agricultural production has been converted back to forests. Managing cropland with conservation tillage sequestered soil organic C at a relatively high rate, especially when conservation tillage systems used cover crops for winter biomass production (Franzluebbers, 2005). The warm, moist conditions throughout the year can allow for intensive cropping that has beneficial effects on soil organic C accumulation. Conversion of land to pasture sequestered even more soil organic C than conservation-tillage cropping systems. There is an urgent need to obtain reliable estimates of N_2O and CH_4 emissions from crop and animal production systems in the region.

Table 1 summarizes regional estimates of the effect of land management on changes in soil organic C and greenhouse gas emissions. All estimates are in $\text{CO}_2\text{-C}$ equivalents, in which positive values are $\text{CO}_2\text{-C}$ equivalents released to the atmosphere and negative values are $\text{CO}_2\text{-C}$ equivalents stored in soil.

... the coordinated effort of GRACenet provides a targeted scientific approach to study soil C sequestration and greenhouse gas emissions.

Climate, in particular, determines the type and amount of vegetation that occurs naturally and that can be managed.

The lack of estimates for various management comparisons in a region indicates a great need for further research. The concentration of soil organic C in agricultural soil was 22 to 36 percent lower than under native condition among the five regions. An estimate of soil organic C sequestration with adoption of conservation tillage was the most complete data set among regions. Soil organic C sequestration with no tillage varied from 0.07 to $-0.48 \text{ Mg CO}_2\text{-C equivalents} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ among regions. More complex cropping systems also led to greater soil organic C sequestration (-0.12 to $-0.29 \text{ Mg CO}_2\text{-C equivalents} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$) than continuous or simple cropping systems. Although livestock grazing contributes to significant land use in all regions, only limited data were available to estimate the effect of management on soil C sequestration and greenhouse gas emission. Conversion of cropland to grassland (or Conservation Reserve Program) had a large positive effect on soil organic C sequestration in most regions (-0.32 to $-1.03 \text{ Mg CO}_2\text{-C equivalents} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$). Grazing of forage had a large positive effect on soil organic C sequestration in the southeastern United States, but a minor negative effect in the southwestern United States, probably due to differences in precipitation that controlled how fast and to what extent plant communities responded to defoliation. Data from the southwestern United States suggest that even though

invasion of grazing lands by leguminous woody plants may not be desirable from a rangeland resource viewpoint, this invasion could sequester

soil organic C at a greater rate than under open grassland.

Although many scientific investigations have been conducted during the past century of agricultural research in North America, there are still large knowledge gaps to be able to make management decisions that will simultaneously: (1) satisfy the economic livelihoods of the farmers that cultivate our land, (2) reduce the threats to the environment from unintended consequences of our human need to produce food and fiber, and (3) protect the quality of the land for generations to come.

New research aims should (1) quantify the effects of a wide range of agricultural management systems on soil organic C sequestration and greenhouse gas emission, (2) develop robust recommendations for improving soil, water, and air quality in North America, and (3) develop novel approaches and unique perspectives in managing agricultural land to achieve both production and environmental goals. The ARS GRACenet project was developed to help achieve these objectives.

Farming carbon

How soil C sequestration and reduction in greenhouse gas emissions might influence the economics of land management decisions remains unknown. In theory, very high C payments could push C sequestration into position as a primary goal for some

agricultural lands, rendering production of agricultural commodities secondary. The Conservation Reserve Program, for example, is a program whereby land is set aside from agricultural production in favor of environmental benefits. It would be reasonable to envision a program that contained soil C sequestration as the primary consideration. For the immediate future, however, it seems likely that the primary economic driver of agricultural lands will continue to be crop or animal production. Tradeoffs among soil C sequestration, net global warming potential, other environmental benefits, and yield would certainly influence decisions of land managers to change production practices for C payments. Thus, commodity yield will be a key measurement in GRACenet.

Research cooperation with programs having similar goals both within the

Table 1. Summary of global warming potential as affected by agricultural management strategies in different regions of North America (adapted from Franzluebbers and Follett, 2005). All units have been adjusted to CO₂-C equivalence. Negative values represent sequestration in soil. Positive values are emission to the atmosphere.

MANAGEMENT COMPARISON	REGION ON NORTH AMERICA				
	NORTH-WEST	NORTH-EAST	CENTRAL	SOUTH-WEST	SOUTH-EAST
<i>As change in soil organic carbon (Mg CO₂-C equivalents • ha⁻¹ • yr⁻¹)</i>					
Conservation vs conventional tillage	-0.27	0.07	-0.48	-0.30	-0.42
More complex cropping systems	-0.12	--	-0.18	-0.29	-0.22
Addition of animal manure ^a	-0.15	---	--	--	-0.72
Addition of N fertilizer ^a	-0.09	--	--	--	-0.18
Conversion of cropland to grass	-0.94	--	-0.56	-0.32	-1.03
Grazed versus ungrazed grassland	-0.16	--	--	0.03	-0.76
Invasion of woody plants in grassland	--	--	--	-0.22	--
<i>As N₂O emission (Mg CO₂-C equivalents • ha⁻¹ • yr⁻¹)</i>					
Crop systems	0.55	0.54	--	--	--
Grass systems	0.09	0.17	--	1.04	--
<i>As CH₄ emission / uptake by soil (Mg CO₂-C equivalents • ha⁻¹ • yr⁻¹)</i>					
All cropping systems	-0.03	0.00	--	--	--

^a Excludes carbon cost of manufacture and distribution

1
 Growing plants serve as a sink for CO₂ by ‘breathing it in’ to make their own food, but eventually much of this CO₂ is released back to the atmosphere when plants decompose. The parts of plants that do not fully decompose are transformed into soil organic matter, and this accumulation of C can be called “soil C sequestration.”



United States and internationally will likely occur. The geographical extent of GRACEnet, use of common procedures, and cooperation with other North American C cycle research programs will result in robust information that can be transferred to end users. Development of scientifically-based conservation technologies will be relevant to national and international policy makers, as well as to agricultural producers and practitioners on local and regional levels.

The joint possibilities of (1) mitigating greenhouse gas emission from agricultural operations and (2) sequestering C in soil organic matter with conservation management have become important reasons to invest in soil.

References Cited

- Environment Canada. 2006. Canada's Greenhouse Gas Inventory, 1990–2003.
- Franzluebbers, A.J. 2005. Soil organic carbon sequestration and agricultural greenhouse gas emission in the southeastern USA. *Soil and Tillage Research* 83:120–147.
- Franzluebbers, A.J. and R.F. Follett. 2005. Greenhouse gas contributions and mitigation potential in agricultural regions of North America: Introduction. *Soil and Tillage Research* 83:1–8.
- Gregorich, E.G., P. Rochette, A.J. VandenBygaart, and D.A. Angers. 2005. Greenhouse gas contributions of agricultural soils and potential mitigation practices in eastern Canada. *Soil and Tillage Research* 83:53–72.
- Johnson, J.M.F., D.C. Reicosky, R.R. Allmaras, T.J. Sauer, R.T. Venterea, and C.J. Dell. 2005. Greenhouse gas contributions and mitigation potential of agriculture in the central USA. *Soil and Tillage Research* 83:73–94.
- Liebig, M.A., J.A. Morgan, J.D. Reeder, B.H. Ellert, H.T. Gollany, and G.E. Schuman. 2005. Greenhouse gas contributions and mitigation potential of agricultural practices in northwestern USA and western Canada. *Soil and Tillage Research* 83:25–52.
- Martens, D.A., W. Emmerich, J.E.T. McLain, and T.N. Johnsen, Jr. 2005. Atmospheric carbon mitigation potential of agricultural management in the southwestern USA. *Soil and Tillage Research* 83:95–119.
- U.S. Department of Agriculture (USDA). 2004. U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1900–2001. Global Change Program Office, Office of the Chief Economist, USDA. Technical Bulletin No. 1907. 164 pp.
- Alan J. Franzluebbers** is an ecologist at the U.S. Department of Agriculture (USDA) Agricultural Research Service (ARS) Southern Piedmont Conservation Research Unit in Watkinsville, Georgia. **Ronald F. Follett** is a supervisory soil scientist at the USDA-ARS Soil-Plant-Nutrient Research Unit in Fort Collins, Colorado. **Jane M.F. Johnson** is a soil scientist at the USDA-ARS North Central Soil Conservation Research Laboratory in Morris, Minnesota. **Mark A. Liebig** is a soil scientist at the USDA-ARS Northern Great Plains Research Laboratory in Mandan, North Dakota. **Edward G. Gregorich** is a soil biochemist at Agriculture and Agri-Food Canada's Central Experimental Farm in Ottawa, Ontario. **Timothy B. Parkin** is a microbiologist at the USDA-ARS National Soil Tilth Laboratory in Ames, Iowa. **Jeffrey L. Smith** is a soil scientist at the USDA-ARS Land Management and Water Conservation Research Unit in Pullman, Washington. **Stephen J. Del Grosso** is a soil scientist at the USDA-ARS Soil-Plant-Nutrient Research Unit in Fort Collins, Colorado. **Michael D. Jawson** is a former national program leader at the USDA-ARS and is currently director at the USGS Upper Midwest Environmental Sciences Center in LaCrosse, Wisconsin. **Dean A. Martens** was a soil scientist (deceased 2005) at the USDA-ARS Southwest Watershed Research Center in Tucson, Arizona.